CCS in the Process Industries

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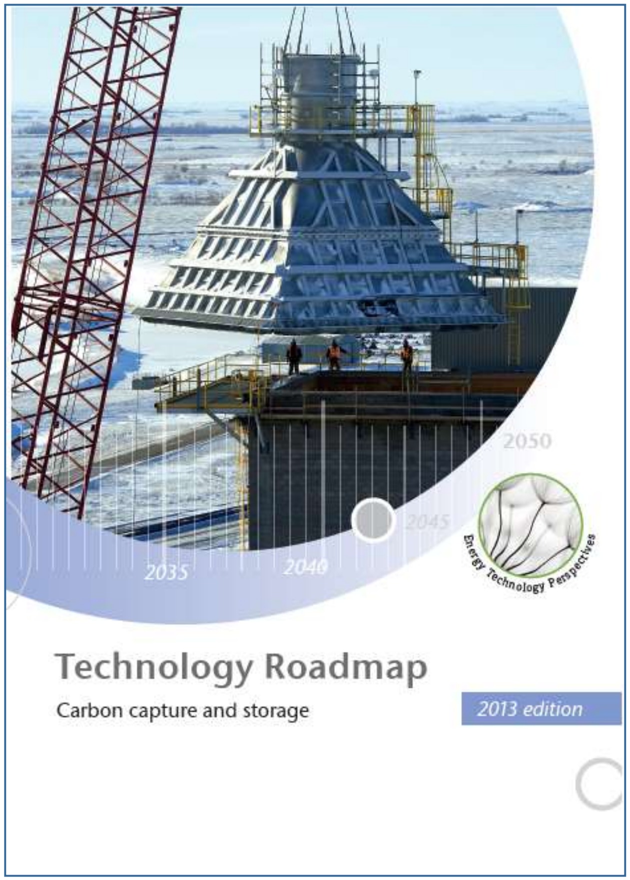
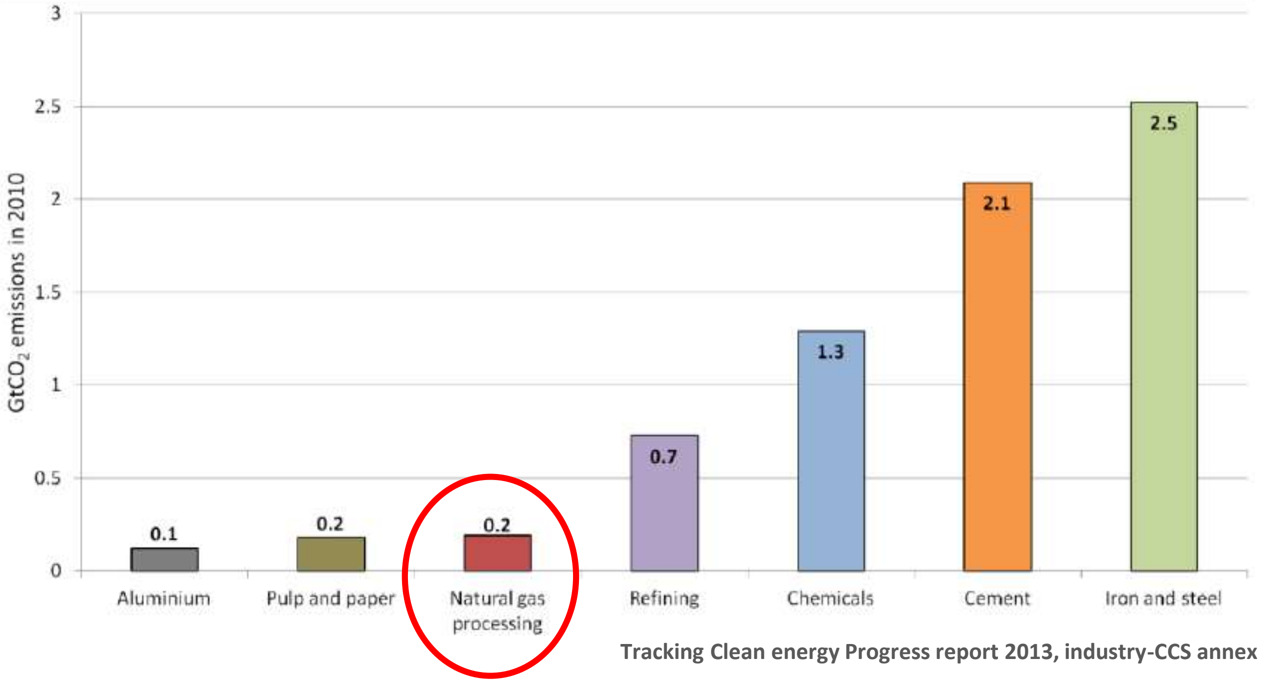
2013 CCS Roadmap: Key findings



- CCS is a **critical component** in a portfolio of low-carbon energy technologies, contributing 14% of the cumulative emissions reductions between 2015 and 2050 compared with business as usual.
- The individual component technologies are generally well understood. **The largest challenge is the integration** of component technologies into large-scale demonstration projects.
- Incentive frameworks are urgently needed to deliver upwards of **30 operating CCS projects by 2020**.
- CCS is not only about electricity generation: 45% of captured CO_2 comes from **industrial applications** between 2015 and 2050.
- The largest deployment of CCS will need to occur in **non-OECD countries, 70% by 2050**. China alone accounts for 1/3 of the global total of captured CO_2 between 2015 and 2050.
- The urgency of CCS deployment is only increasing. **This decade is critical** in developing favourable conditions for long-term CCS deployment.

Rationale for CCS: Only large-scale option for many industries

Figure 1. Global emissions from the seven most CO_2-intense industrial sectors in the IEA *Energy Technology Perspectives* analysis



Tracking Clean energy Progress report 2013, industry-CCS annex

CCS is the only large-scale mitigation option for many industrial sectors.

EU Zero Emission Platform Report 2013

- EU 2011 Roadmap for a competitive low carbon economy in 2050,
- Emission reductions will be required to take place in all sectors,
- CO_2 emissions from the industrial sectors reduced by 34% to 40% by 2030, and by between 83% to 87% by 2050.
- Only CCS can provide the required large-scale emission reductions in EU industry

Early Commercial Application of CCS (Monitored)

Sleipner
1Mt/y CO_2

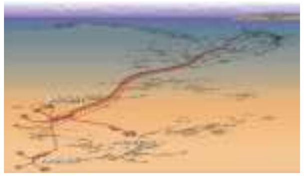
Weyburn
2.5 Mt/y CO_2

In-Salah
1.2 Mt/y CO_2

Snohvit
0.7Mt/y CO_2

Gorgon
4Mt/y CO_2

350km overland pipeline



160km sub sea pipeline

1996 1998 **2000** 2002 **2004** 2006 **2008** 2010 2012 2014 2016 2018

Industry Sector drivers

- CO_2 removed to meet pipeline standards
  - High purity CO_2 stream
- Additional costs of injection low relative to power plant
  - Norway = offshore emission tax $35/t
- CO_2 capture plants in close proximity to storage resources
- Industry has gas injection/storage reservoir expertise

Outcomes and Developments

- Sleipner nearly 20 years continuous operation
  - Follow monitoring developments
    - IEAGHG Monitoring Network meetings
    - International Journal of Greenhouse Gas Control
- Sleipner, Snohvit, In-Salah, Gorgon all use Amine scrubbing technology
  - Land or platform based
- Lula project – uses membrane technology for CO_2 separation
  - Modular lighter design for use on the floating platform
- IEAGHG study currently underway that is looking at new capture technology options for gas processing
  - Cost, size etc.
  - Published - 3rd Quarter 2015
- Potential new developments in South East Asia

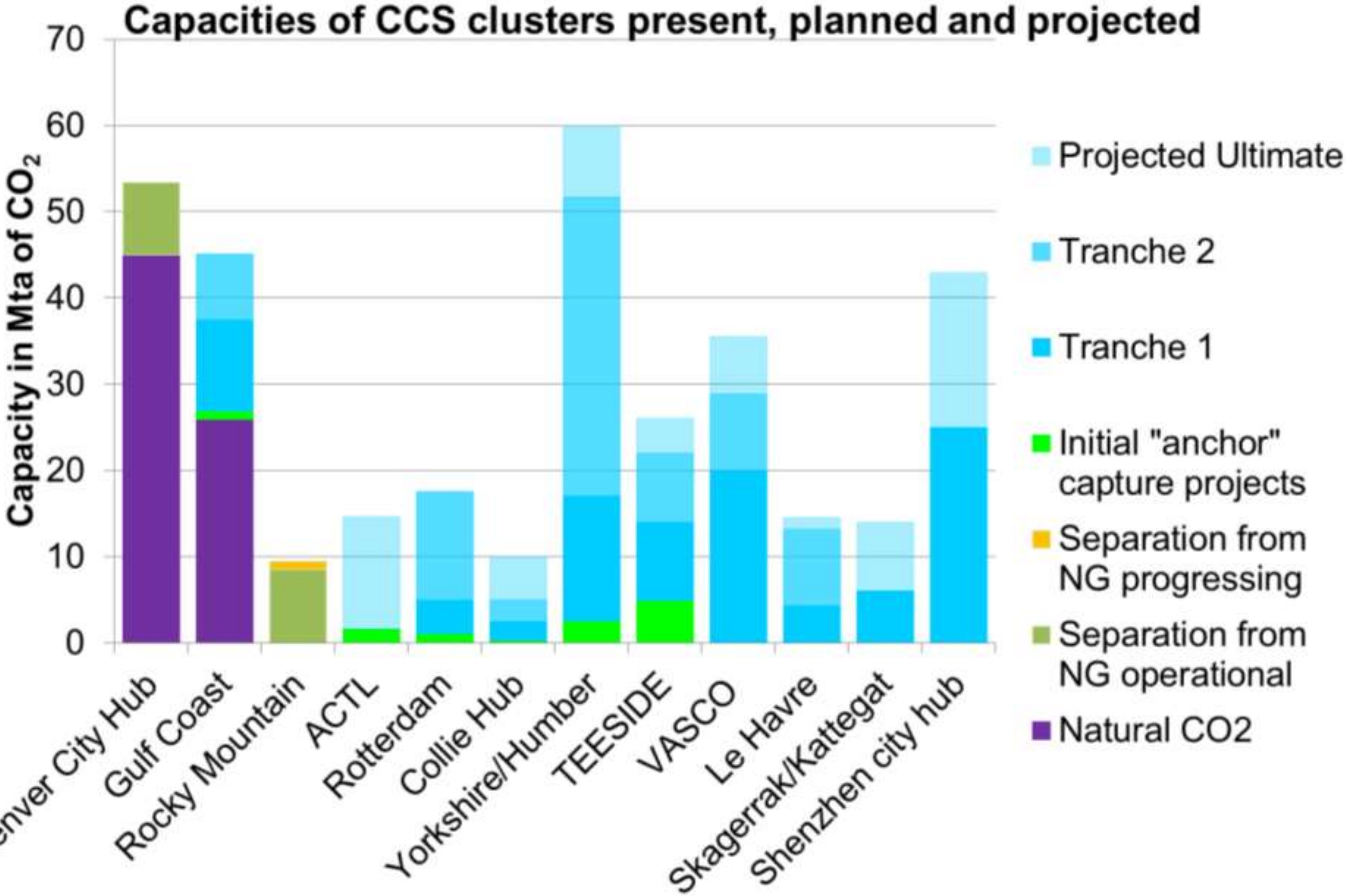
EU Industry considerations

- Core business is making globally competitive products e.g. steel, cement, chemicals…….
- Is there a business case for CCS in industry?
  - Probably not –price on CO_2 currently too low
- Industry has no experience of transport and storage
  - same as power sector initially
- Ideally would like a storage company to handle out of gate storage
  - No market outside North America such as EOR
  - In EU therefore no such companies currently exist

Infrastructure considerations

- Each industrial site will be site specific
  - No generalities possible like CCS Ready Guidelines for Power sector
- Need a gas gathering system?
  - More than one stack
  - Central capture plant or multiple?
  - Or do you target most competitive single source – 45% capture enough?
- Development of transport infrastructure
  - Strategic planning?
  - Who pays?
    - NER400 in Europe?
    - CO2-EOR operators/companies in North America
- Project Clusters have significant potential going forward
  - Waste heat utilisation and process cost savings
  - Pipeline accessibility

IEAGHG CCS Cluster Project



Study Outcomes

- Most successful Cluster projects are based on CO_2 EOR application
- Cost reduction can be achieved by combining infrastructure e.g. CO_2 pipeline and pooling services (maintenance and operation of capture facility)
- Long term funding is required, in order to maintain momentum in the project and keep the key staff members
- Good CCS cluster locations should be in the position to attract international funding
- It is required to develop a mechanism and structure of international investment to widen the support for cluster projects

Heavy Industry CCS activities

- **Steel sector**
  - 1st Steel industry CCS workshop with VDEH in Germany in November 2011
  - Techno- economic assessment of CCS in steel sector – completed 2013
    - Included a case evaluating Oxy-Blast Furnace with TGR & MDEA CO_2 Capture
  - Overview of the current state and future development of CO2 capture technologies in the Iron Making Process, TR3, April 2013
  - 2nd Steel industry CCS workshop in Japan November 2013 – collaboration with WSA and IETS
- **Cement Industry**
  - Techno- economic assessment completed in 2008
  - Studies on barriers to implementation completed in 2013 (with GCCSI)
- **Oil Refining Sector**
  - Techno- economic assessment to underway
    - Report due mid 2016
- **Industrial sources of Hydrogen**
  - State of the art review completed
  - Techno-economic assessment now underway – due mid 2015

Costs of CO_2 Capture

- Costs estimated for a 1Mt/y cement plant in N-W Europe
- Post combustion capture (PCC)
  - €107/t of CO_2 emissions avoided
  - Could be reduced to €55/t by locating a cement plant next to a power plant and using a low sulphur raw meal
  - Alternative CO_2 capture solvents could significantly reduce costs
- Oxy-combustion
  - €60/t CO_2 emissions avoided
- Capture costs for PCC could be reduced by up to 50% if waste heat could be integrated from other sources
- At a larger Asian type plant 3 Mt/y costs could be 30-40% lower than EU case
  - Oxy fuel case - €23/t CO_2 emissions avoided

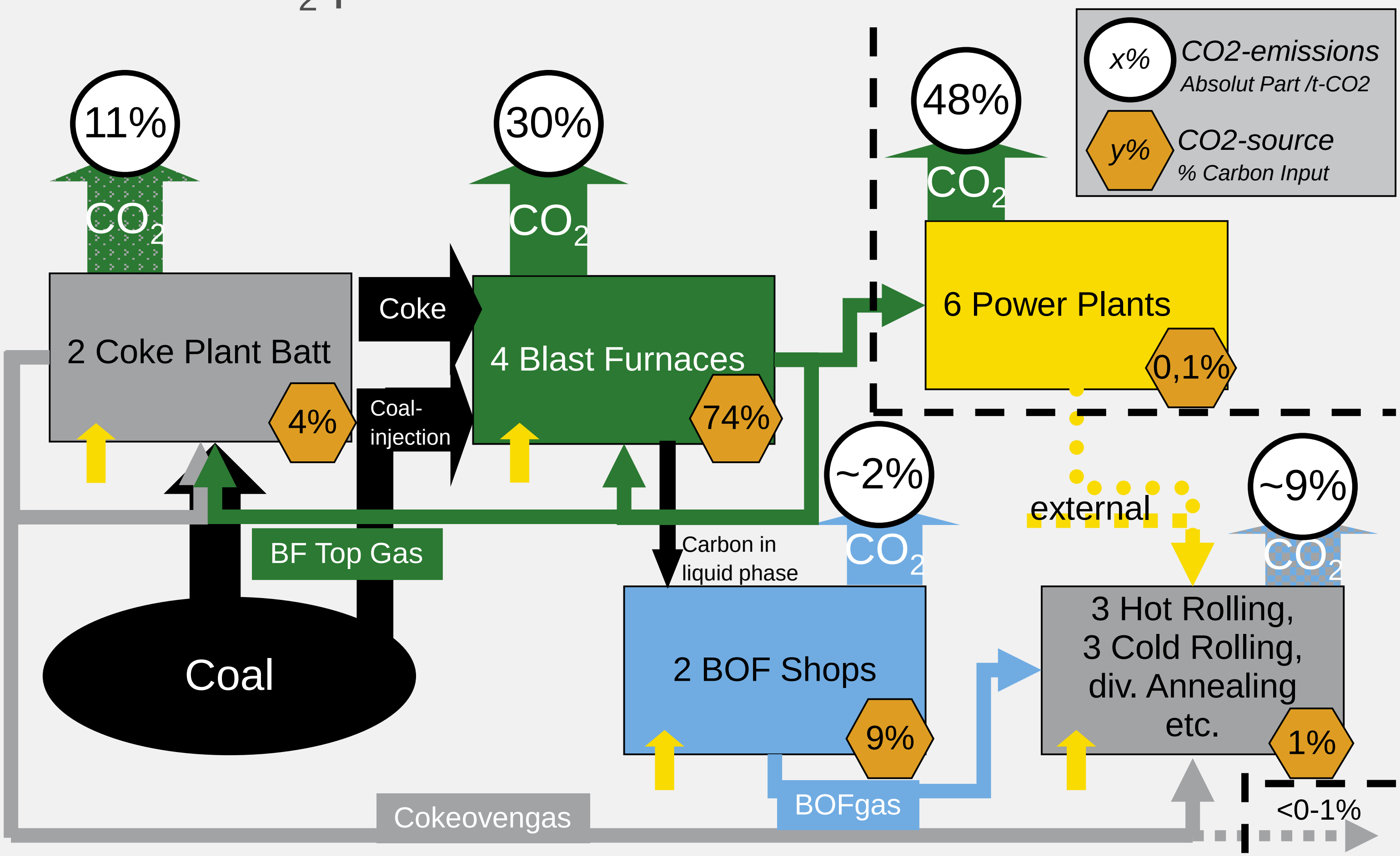
CO_2 Capture at Cement Plants

Oxy-combustion Pilot Plant Project

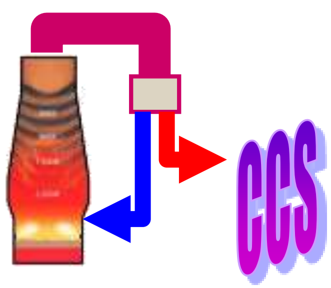
- Feasibility of oxy-combustion at cement plants investigated by Lafarge, FLSmidth and Air Liquide
- Pre-calciner pilot plant at Dania, Denmark successfully modified and operated with oxy-combustion
  - 2-3t/h raw meal (~1t/h CO_2)
  - Pre-calciner accounts for 90% of CO_2 from carbonate decomposition and 60% of fuel-derived CO_2 from a cement plant
- Feasibility and costs of retrofitting oxy-combustion calciner to Lafarge commercial cement plant at Le Havre was assessed
  - €62/t CO_2 captured (consistent with IEAGHG studies)
- Technology now ready to move into the demonstration phase
  - Next stage would be a 1-2 year FEED study
  - Currently no viable business case for CCS at European cement plants

ThyssenKrupp Steel Europe – Main CO_2-Emitters (schematically)

up to 20 mio t CO_2 p.a.

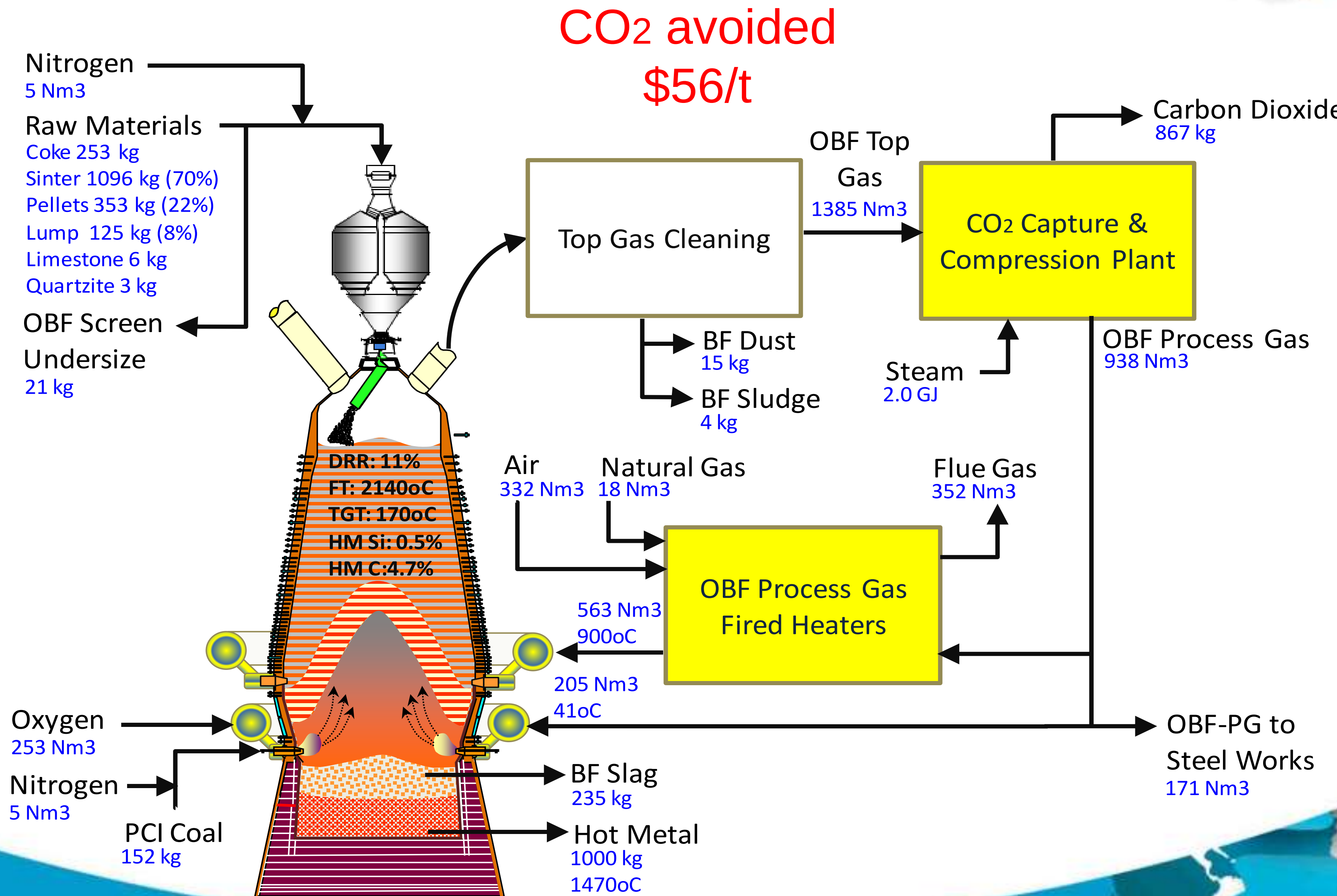


The 4 ulcos process routes

Coal & sustainable biomass		Natural gas	Electricity
Revamped BF	Greenfield	Revamped DR	Greenfield
ULCOS-BF 	HIsarna 	ULCORED 	ULCOWIN ULCOLYSIS 
Pilot tests (1.5 t/h) Demonstration under way	Pilot plant (8 t/h) start-up 2010	Pilot plant (1 t/h) to be erected in 2013?	Laboratory

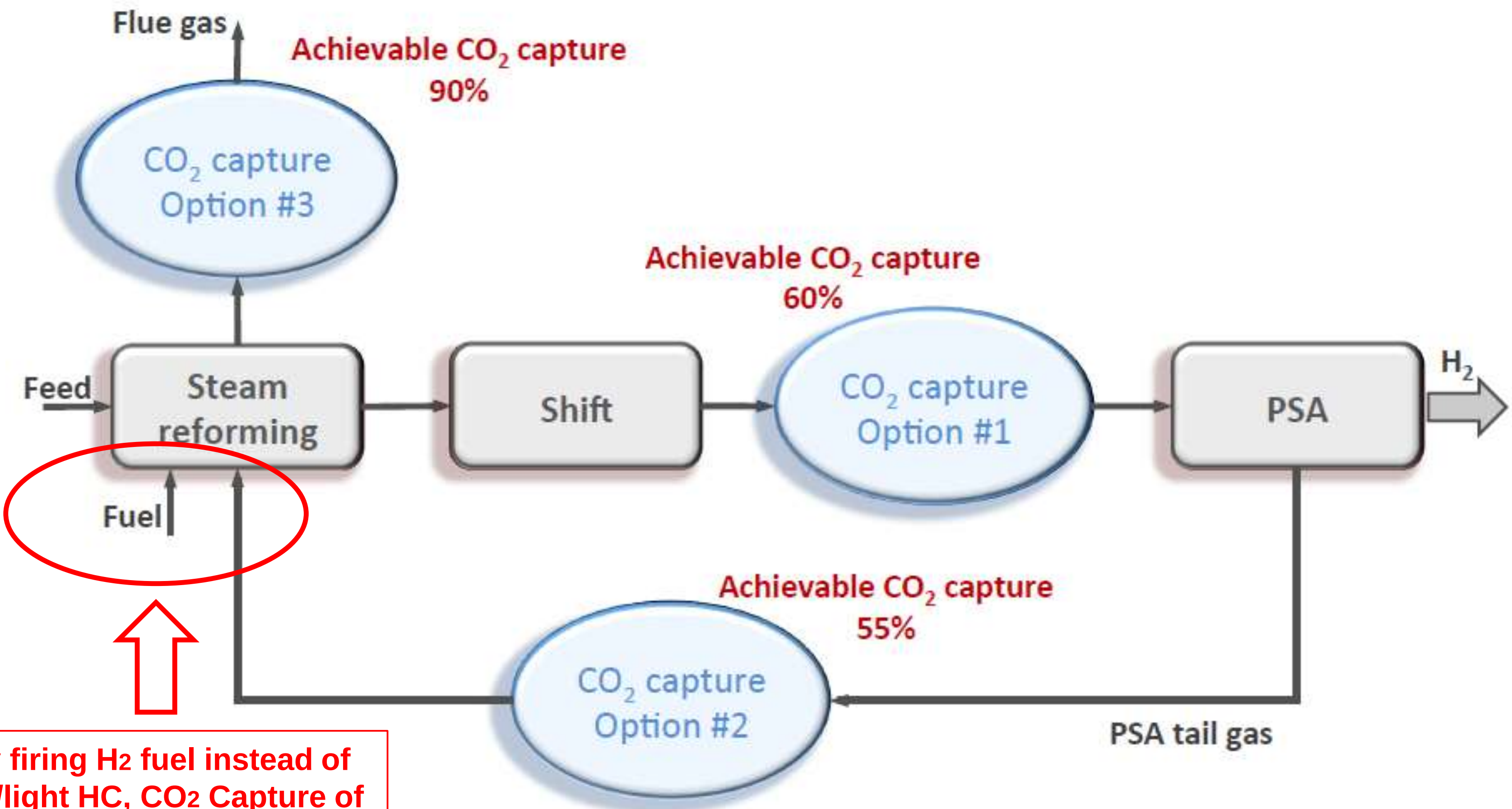
Oxy-Blast Furnace Operation

(Picture of OBF courtesy of Tata Steel)



SMR with CO_2 Capture

(Picture Courtesy of AmecFW)



By firing H_2 fuel instead of NG/light HC, CO_2 Capture of ~90% could be achievable for options #1 and #2.

Review of Large Scale Demo and Pilot CCUS Projects from SMR Based H_2 Production

- Large scale demo projects
  - AP Port Arthur Project (USA)
    - Operational - ~1 million tpy CO_2 captured for EOR
  - Shell Quest Project (Canada)
    - Under construction - ~ 1 million tpy CO_2 captured and stored (on-shore) in saline acquifer
- Large scale pilot projects
  - AL Port Jerome Project (France)
    - Under commissioning - ~100k tpy CO_2 captured for sale as food grade CO_2.
  - Japan CCS Tohokamai Project (Japan)
    - Under construction - ~200k tpy CO_2 captured and stored (off-shore) in saline acquifer

Observations to date

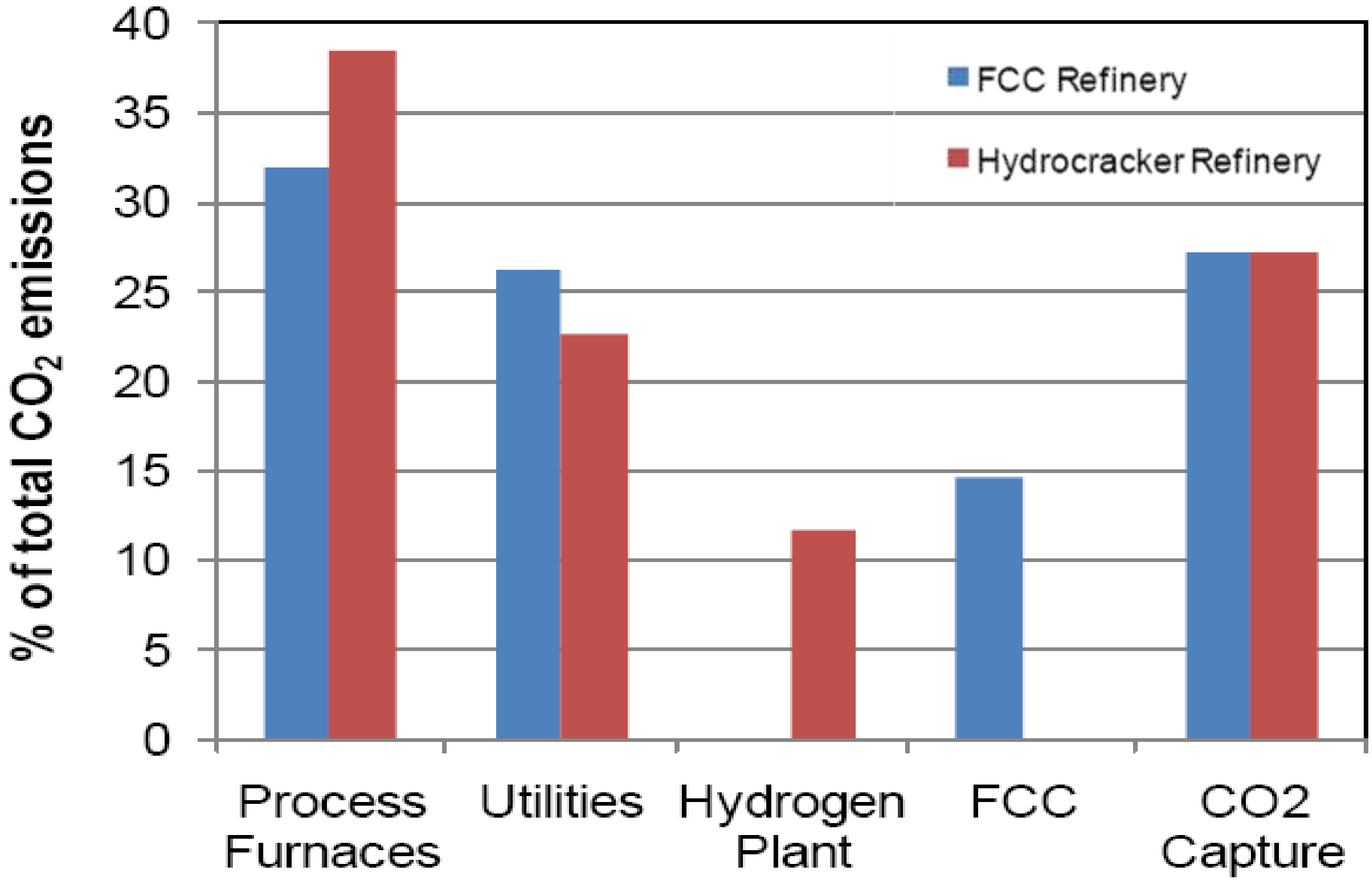
- Capture of CO_2 from SMR is not new.
  - Low hanging fruit but **<u>not cheap</u>**
- Large scale demonstration of the integration of CO_2 capture, transport and storage is important; and <u>this has been achieved.</u>
- Development of new novel technologies are on-going to reduce cost

Picture from Air Products

Figure 4. Repsol, Spain, H_2 plant with partial CO_2 capture.

- Repsol SMR Plant (67,000 Nm^3/h H_2)
- Operational since 2002
- ~60,000 TPD of CO_2 captured via MDEA from syngas for food market

Distribution of CO_2 Emissions for Refineries with CO_2 Capture



Data from CONCAWE 2011

Challenges

- Variation of Refinery Capacity and level of Complexity should also lead to variation of overall CO_2 emissions from oil refineries
  - In Europe capacity varies from 0.4 Mtpy to 5.5 Mtpy CO_2. (CONCAWE)
- Diverse point sources of CO_2
  - Oxy fire furnaces – CCP project
  - Central CHP plant – Statoil Mongstad
- Wide ranging percentage/concentration of CO_2 from different sources

Summary

- Provided an overview of IEAGHG completed and on going work in this area
  - Reference material on our web site
- First to publish “transparent” costs in cement and steel sectors
- Industry under a range of commercial pressures
  - Cutting CO_2 emissions just another problem
- Complex systems: is no one fits all engineering solution
- Likely only a partial reduction of emissions is finically viable
- Capture ready guidelines for industry?

Thank you, any Questions?

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